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Description

This invention relates to the production of cellular polymeric structures, and more particularly to improvements in the manufacture of polyimide foams.

Over the years, considerable effort has been devoted to the development of technology for producing polyimide foams. Such materials are generally produced by forming a polyimide precursor, usually an essentially equimolar mixture of a lower alkyl ester of a tetracarboxylic acid and one or more primary diamines, and subjecting a bed or body of this polyimide precursor mixture to a temperature sufficient to cause the development of a foamed polymer structure through the generation and evolution of gaseous material within the body of the precursor. See for example U. S. Pat. Nos. 4,153,783, 4,296,208, 4,305,796, 4,439,381 and Re.30,213. Although the foaming operation may be performed in thermal ovens or by use of dielectric heating, to date use of microwaving as described in U. S. Pat. Nos. 4,305,796 and 4,439,381 has proven most successful.

Despite the intensity and magnitude of the efforts to improve upon the technology of polyimide foam production, a number of difficulties have defied solution. Chief among these has been the inability to achieve consistently high yields of usable foam from the polyimide precursor. As formed, the polyimide leaves the oven in the form of a "bun" which has a crust over its outer surface which must be cut away in order to expose the interior cellular mass of cured polyimide foam. Unfortunately, blow holes, striations and other physical defects are often encountered in the buns, which means that the defective zones within the bun must be trimmed away and discarded, often with a considerable loss of raw materials and plant throughput. Complicating the problem has been the erratic nature of these events -- only after the bun had been made and trimmed can it be determined whether the production run has been successful or not. Moreover, successive runs conducted under apparently the same conditions may give rise to vastly different results. In one case the yield of specification grade foam may be reasonably good, yet in the very next run it may be unacceptably low.

A most worthwhile contribution to the art would thus be the discovery of a way of improving the yields of specification grade polyimide foam on a consistent basis from one run to the next. This invention is believed to fulfill this need.

Provided by this invention are improvements in microwave-based foaming processes. In accordance with one embodiment of this invention before and during the time the body of polyimide precursor is exposed to microwave radiation, the body of polyimide precursor and of the foam structure as it is developing therefrom are kept under a substantially vapor-impermeable microwave-compatible shroud that does not substantially restrict or impede development of the foam structure and prevents the surface of the foam from drying out and becoming hard and crusty as it would if left exposed. For this purpose use may be made of a shroud composed of a polymer film, such as polyvinyl chloride (PVC), polyvinylidene chloride, polyethylene, polypropylene, nylon or polyethylene terephthalate, PVC being preferred. The suitability of any given polymer film can readily be determined by simply running a few preliminary small scale foaming experiments using various candidate films to see which ones result in the generation of desirable foam structures during the microwaving operation.

In practice suitably-sized sheets or strips of the film are placed over the top and around the sides and ends of the body of polyimide precursor before the microwave radiation is applied. The film should not be applied so that it excessively constricts the expansion of the developing film structure. Films having stretch characteristics are useful in this regard, provided of course that they are made of materials that can withstand the temperatures that are developed in the microwaving operation.

Several beneficial mechanisms are believed to occur because of the use of a shroud. In the first place, polyimide precursors, especially when in powder form, are very hygroscopic. Thus the film is believed to prevent the precursor from picking up too much moisture from the atmosphere before the microwave radiation is applied. Secondly, when a body of polyimide precursor is exposed to the microwave radiation, the development of a foamed polymer structure is caused through the generation and evolution of gaseous material within the body of the precursor. This gaseous material initially is predominantly vaporous alcohol (e.g., methanol or ethanol) being liberated from the ester component in the precursor, along with some water vapor which is also liberated in the reactions taking place within the precursor mixture. In the absence of the vapor-impermeable microwave-compatible shroud this gaseous material leaves the surface of the developing foam and allows the surface to dry out and become hard and crusty, which in turn impedes proper development of additional foam within the interior of the bun, and provides areas for excessive heat build up with consequent adverse effects on foam quality. Careful observation of the surface of buns developing when encased by a shroud pursuant to this invention indicates that the surface does not dry out as it would if left exposed, and in fact in some cases the surface appears to have become wet with

condensed vapor from the alcohol and/or water enriched atmosphere which the shroud maintains around the developing foam. It will be understood and appreciated, of course, that this invention is not to be limited by any particular theory or to any particular mechanism of operation. The foregoing explanation conforms to the observations made to date and is believed to be a rational explanation of why the shroud performs so successfully. However this invention is not intended to be, nor should it be, limited by theoretical considerations -- the invention works, and it works well, irrespective of exactly how it works.

Another way of adapting the concept of the shroud to the microwaving operation is to maintain a suitable quantity of the precursor, whether in powder or liquid form, encased in a sealed bag or pouch of vapor-impermeable, microwave-compatible material, such as a plastics bag or pouch, from around the time it is formed and to use this bag or pouch of precursor in the microwaving step. In this way all of the foregoing benefits of the shroud are achieved and additionally, handling, storage and transport of the precursor are facilitated.

In accordance with, and as an outgrowth of, the use of a shroud, another embodiment of this invention provides a method of producing a foamed polymer structure which comprises:

(i) subjecting a body of polyimide precursor to microwave radiation of intensity sufficient to cause the development of a foamed polymer structure through generation and evolution of gaseous material within the body of the precursor, and

(ii) maintaining the precursor and the foam structure developing therefrom, concurrently with subjecting it to microwave radiation, under an atmosphere enriched in vapors of a C_1 to C_4 alcohol.

The operation of (ii) hereof may be effected simply by use of the shroud in the manner described hereinabove. Alternatively, the foaming step may be conducted in an enclosed chamber through which an atmosphere enriched in vaporous C_1-C_4 alcohol is circulated so that the developing foam structure is itself encased in this enriched vaporous atmosphere. Use of a very fine spray or mist of alcohol in a suitably-designed microwave chamber is also possible. The alcohol-enriched atmosphere or spray or mist of alcohol may contain a suitable quantity of water in vapor or mist form.

In accordance with, and as an outgrowth of, the use of a shroud, still another embodiment of this invention provides a method of producing a foamed polymer structure which comprises:

(i) subjecting a body of polyimide precursor to microwave radiation of intensity sufficient to cause the development of a foamed polymer structure through generation and evolution of gaseous material within the body of the precursor, and

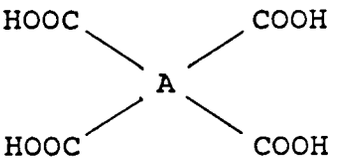
(ii) preventing at least a substantial portion of the exposed surfaces of said precursor and the foam as it is developing therefrom, concurrently with subjecting it to microwave radiation, from drying out by keeping such surfaces wetted by a C_1 to C_4 alkanol in quantity insufficient to impede the development of the foam.

As in the case of the embodiment described in the immediately preceding paragraph, the operation of (ii) above may be effected simply by use of the shroud in the manner described hereinabove. Alternatively, the foaming step may be conducted in an enclosed chamber in which an atmosphere saturated or almost saturated by vaporous C_1-C_4 alcohol is maintained so that the developing foam structure is itself encased in an atmosphere that will not carry away the alcohol being liberated in the bun. Use of a very fine spray or mist of alcohol in a suitably-designed microwave chamber is also a useful alternative. Here again the alcohol-enriched atmosphere or spray or mist may be composed of a mixture of the alcohol and the water.

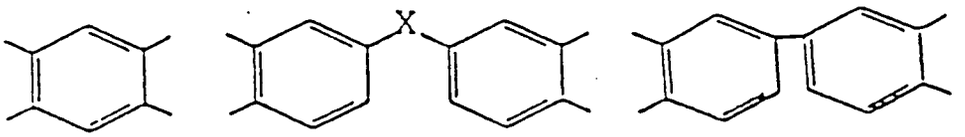
Preferred precursors for use in the embodiments of the immediately preceding two paragraphs are comprised of a lower alkyl ester of an aromatic tetracarboxylic acid and at least one aromatic or heterocyclic primary diamine. It is also preferable to employ in those embodiments a precursor that is initially in powder form.

The polyimide precursors used in the practice of this invention can vary widely in composition. In general, they are composed of a mixture comprising at least (i) one or more organic tetracarboxylic acids or derivatives thereof, and (ii) one or more organic diamines co-reactive therewith, preferably an aromatic or heterocyclic or primary diamine. Components (i) and (ii) are usually present in the mixture in essentially stoichiometric quantities.

The organic tetracarboxylic acids or derivatives thereof are preferably based on aromatic tetracarboxylic acids having the general formula:



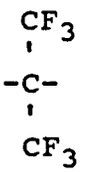
where A is a tetravalent organic group. The tetravalent organic group A is preferably one having one of the following structures:



wherein X is one or more of the following:



-O-; -S; -SO_2-; -CH_2-; -CH_2CH_2-;



Preferred among the tetracarboxylic acid esters are the alkyl esters of 3,3',4,4'-benzophenone tetracarboxylic acid, most preferably the lower alkyl diesters thereof. Mixtures of two or more aromatic esters, most preferably predominating in diesters, may be employed, if desired.

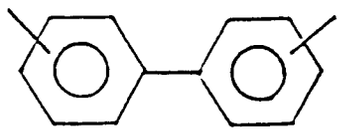
It is also possible, in accordance with this invention, that the tetracarboxylic acid derivative employed in the manufacture of the polyimide foams be a caprolactam as taught by U. S. 4,161,477, 4,183,838 and 4,183,839. As described in those patents, bis-imide is formed by reaction of a tetracarboxylic acid dianhydride with an oxoimine such as caprolactam and then reacted with the diamine or diamines to produce the desired polyimides. The caprolactam is displaced during the reaction, in much the same way as is the ester portion of the tetracarboxylic acid ester.

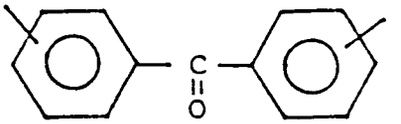
The tetracarboxylic acid derivative used in the manufacture of the polyimide foams pursuant to this invention may also be an N-substituted imido acid ester of the tetracarboxylic acid as taught by U. S. 4,647,597 and 4,656,198. As described in those patents, the N-substituted imido acid ester may be formed by reacting an aromatic tetracarboxylic acid dianhydride with an amino acid and an alcohol or mixture of alcohols. As further taught in those patents, on reaction of the imido acid ester with the diamine or diamines, the acid ester group bonded to the nitrogen atom of the N-substituted imido acid ester is displaced so that the desired polyimide is formed.

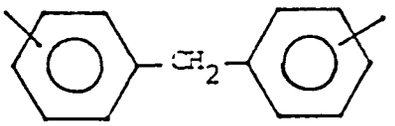
The organic diamines with which the foregoing mixture of tetracarboxylic acids or derivatives is employed may be represented by the formula:

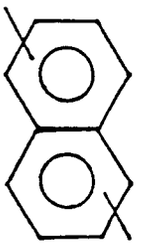
H_2N-R'-NH_2

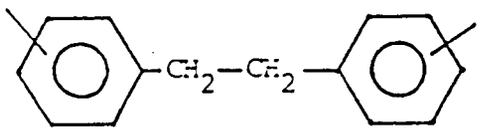
wherein R′ is an aromatic group containing 5 to 16 carbon atoms and containing up to one hetero atom in the ring, the hetero atom being nitrogen, oxygen or sulfur. Also included are aromatic groups such as:

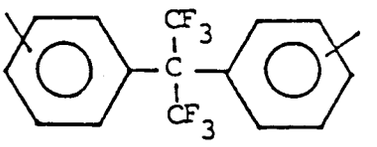


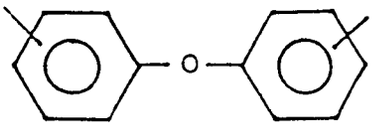


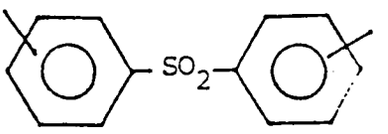












Representatives of such diamines include:
2,6-diaminopyridine;
3,5-diaminopyridine;
3,3′-diaminodiphenylsulfone;
4,4′-diaminodiphenylsulfone;
4,4′-diaminodiphenylsulfide;
3,3′-diaminodiphenylether;
4,4′-diaminodiphenylether;
meta-phenylenediamine;
para-phenylenediamine;
4,4′-methylene dianiline;
2,6-diamino toluene;
2,4-diamino toluene.

It is also possible and sometimes desirable in the preparation of the polyimide precursors of this invention, to include in the reaction mixture one or more aliphatic diamines. Such aliphatic diamines are preferably alpha-omega diaminoalkanes having the formula:

$H_2N\text{-}(CH_2)_n\text{-}NH_2$ (I)

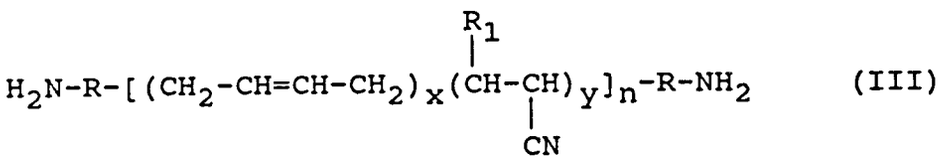
wherein n is an integer from 2 to 16. Representatives of such diamines include 1,3-diaminopropane, 1,4-diaminobutane, 1,5-diaminopentane, and 1,6-diaminohexane.

In place of or in addition to the foregoing aliphatic amines, use can be made of aliphatic etherified polyamines of the type polyoxypropylene amines having the formula:

$H_2N\text{-}CH(CH_3)CH_2\text{-}[OCH_2CH(CH_3)]_x\text{-}NH_2$ (II)

wherein x varies from 1 to 5 carbon atoms.

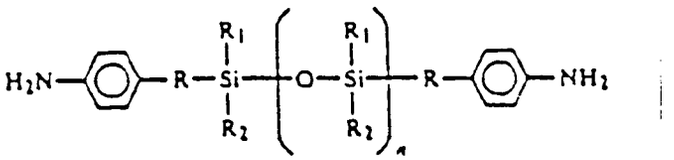
Other useful primary diamines which may be included in the products of this invention include amino-terminated butadiene-nitrile copolymers having the general formula:



$$H_2N\text{-}R\text{-}[(CH_2\text{-}CH{=}CH\text{-}CH_2)_x(CH(R_1)\text{-}CH(CN))_y]_n\text{-}R\text{-}NH_2 \qquad \text{(III)}$$

wherein R is either a phenylene group or an alkylene group, R_1 is hydrogen or methyl, and x and y are each independently integers ranging from 1 to 25 and n is an integer, preferably below 20. In these copolymers it is preferred that butadiene constitute at least 50% by weight of the butadiene and nitrile monomer. The nitrile monomer copolymerized with the butadiene can either be acrylonitrile or methacrylonitrile. Such copolymers generally have low molecular weights, preferably less than 3,000 to insure that they are sufficiently fluid to react in the formation of the polyimide as well as sufficiently fluid so as to be capable of foaming.

Still another type of primary diamines which may be included in the products of this invention is the aromatic amino-terminated silicones, such as those having the general formula:



wherein R is a C_2 to C_6 alkylene group, R_1 and R_2 are each independently lower alkyl containing 1 to 3 carbon atoms and n is an integer from 1 to 4.

Another preferred category of diamines which may be utilized in forming the foams of this invention are the diesters of an amino-substituted aromatic carboxylic acid and a polymethylene glycol. Such diesters may be represented by the general formula:

$H_2N\text{-}ArCOO\text{-}R\text{-}OOCAr\text{-}NH_2$ (V)

wherein R is an alkylene group (which may be branched or straight chain) and which preferably contains from 3 to 8 carbon atoms, most preferably trimethylene; and Ar is an aromatic group which may be composed of one or more fused or non-fused benzene rings which in turn may carry suitable substituents (e.g., nitro, alkoxy) in addition to the primary amino groups.

A few exemplary diesters of this type include:
ethylene glycol-4-aminobenzoic acid diester;
ethylene glycol-3-aminobenzoic acid diester;
ethylene glycol-2-aminobenzoic acid diester;
trimethylene glycol-3-aminobenzoic acid diester;
trimethylene glycol-2-aminobenzoic acid diester;

trimethylene glycol-3-amino-2-nitrobenzoic acid diester;
tetramethylene glycol-3-amino-4-nitrobenzoic acid diester;
tetramethylene glycol-3-amino-5-nitrobenzoic acid diester;
tetramethylene glycol-4-amino-2-nitrobenzoic acid diester;
1,5-pentanediol-4-amino-3-nitrobenzoic acid diester;
1,6-hexanediol-5-amino-2-nitrobenzoic acid diester;
neopentyl glycol-4-amino-2-methylbenzoic acid diester;
1,8-octanediol-4-amino-2-propylbenzoic acid diester;
1,9-nonanediol-3-amino-4-methylbenzoic acid diester;
1,10-decanediol-4-(4-aminophenyl)benzoic acid diester.
Mixtures of such diesters may be employed.

A particularly preferred diester of this type is the diester of trimethylene glycol (1,3-propanediol) and 4-aminobenzoic acid.

In the practice of this invention the organic tetracarboxylic acid preferably in the form of its diester, most preferably from methanol or ethanol, is reacted with the above-referred-to amine(s) to form a prepolymer in the form of a consolidated, fragile foam structure, which is then subjected to additional heating in order to effect imide formation and thereby cure the polymer. When using the tetracarboxylic acid ester this operation can be conducted either in the presence or absence of an added blowing agent to provide the desired polyimide foam.

The relative proportions used in the preparation of the precursors and polymers of this invention can be varied. In general, it is preferred to employ essentially stoichiometric proportions as between the mixture of tetracarboxylic acids or derivatives thereof and the primary diamine(s). However, non-stoichiometric mixtures can be used although the excess of the reactant present in excess usually does not participate in the reaction. As noted above, 1 to 40 mol percent (preferably 10 to 30 mol percent, most preferably about 20 mol percent) of the combination of tetracarboxylic acids or derivatives thereof employed is composed of one or more dicarboxycyclohexenyl succinic acids or their derivatives. The balance of the combination is preferably composed of one or more aromatic or heterocyclic diamines with or without the addition of still other diamines, for example diamines of the type referred to hereinabove in Formulas I, II, III, IV and V, or any mixture thereof. Usually the overall combination of amines will contain no more than about 10 mol percent of the diamines of Formulas I, II, III and IV. In the case of diamines of Formula V, these may comprise up to about 40 mol percent of the mixture of diamines used.

In accordance with one preferred form of the invention, use is made of a combination of aromatic amines, one of which is a nitrogen heterocyclic diamine, preferably 2,6-diaminopyridine and/or 3,5-diaminopyridine, while the other is a diamine containing two benzene rings, preferably 4,4'-methylenedianiline and/or 4,4'-oxydianiline. When using a combination of aromatic amines in accordance with this concept, the mol ratio of the non-heterocyclic diamine to the nitrogen-containing heterocyclic diamine is within the range of 1.0 to 3.0, and preferably 1.5 to 2.8.

When using a lower alkyl ester of the tetracarboxylic acid, the resulting alcohol produced in the reaction as well as the water released during the reaction can be used as the blowing agent during polymerization to form the desired polyimide foams. Alternatively, use can be made of any of a variety of organic or inorganic blowing agents. By use of a solid blowing agent such as Celogen TSH, Celogen OT, Celogen AZ 130, Celogen RA, Celogen HT 500, Celogen HT 550 (Celogen® is a registered trade mark), sodium bicarbonate, benzenesulfonyl hydrazide, boric acid, benzoic acid, and Expandex 5 PT (registered trade mark), of controlled particle size, the homogeneity of the cellular structure of the resulting polyimide foam can be more accurately controlled. Preferred for such use are solid blowing agents which have been subjected to ball milling or other grinding so that the blowing agent is less than 200 μm (microns) in diameter, with 98 percent of the blowing agent particle sizes being less than 150 μm (microns) in diameter.

The chemical compositions of the blowing agents identified by trade name above follow:

Blowing Agent (registered trade marks)	Chemical Composition
Celogen TSH	toluenesulfonyl hydrazide
Celogen OT	p,p'-oxybis(benzenesulfonyl hydrazide)
Celogen AZ 130	azodicarbonamide
Celogen RA	p-toluenesulfonyl semicarbazide
Celogen HT 500	a modified hydrazine derivative
Celogen HT 550	hydrazol dicarboxylate
Expandex 5 PT	5-phenyltetrazole

Variations in the concentration of the blowing agent can be used to achieve specific densities and ILD values. Concentrations of up to 10 percent based on the weight of the polyimide precursor, and preferably 1 to 5 percent, can be employed. A concentration of about 2.5 weight percent is particularly preferred.

Hydrated organic compounds of the type referred to in U. S. 4,621,015 may also be used as blowing agents in the process.

In the practice of this invention, it is possible to include in the reaction mixture various filler and/or reinforcing materials. For example, graphite, glass and other synthetic fibers can be added to the composition to produce a fiber-reinforced product. Microballons may be added for density adjustment, if desired. It is frequently desirable to employ a surfactant thereby increasing cellular structure stability and uniformity, and increase fatigue resistance and make the foam more flexible and resilient. The nature of such surfactants for this use is well known and reported in the patent literature.

Although not necessary, for some applications it is desirable to add a suitable quantity of a flame retardant material to the formulation in order to still further increase the flame resistance of the resultant foam.

In preparing the precursors of this invention, it is preferred to employ the procedures and spray drying techniques described in U. S. 4,296,208.

The temperatures at which the precursor is converted to the polyimide foam are generally those temperatures used in the preparation of other polyimide polymers. As a general rule temperatures ranging from 200 to 400 °C can be used, with heating times from 5 to 60 minutes or longer. As those skilled in the art will appreciate, the time for carrying out the reaction is somewhat dependent upon the reaction temperature, higher temperatures enabling the use of shorter reaction times. It is also possible to heat to a lower temperature in the first stage of the reaction and then to higher temperatures in the later stages.

Heating can be carried out in a conventional oven if desired. Alternatively, the foaming and curing of the precursor into a foamed polyimide polymer can be effected by means of microwave heating. In this technique, the precursor is exposed for 1 to 120 minutes to radio frequencies within the range of 915 to 2450 MHz, with the power output ranging from 1 to 100 kW. The power output to prepolymer weight ratio generally falls within the range of 0.1 to 10 kW per kg.

Having described the basic concepts of the invention, reference is now made to the following examples which are provided by way of illustration, but not by way of limitation of the practice of the invention.

In the following examples the polyimide precursor powder was composed of 4,4'-methylenedianiline (MDA), 2,6-diaminopyridine (DAP) and benzophenone tetracarboxylic acid dimethyl ester (DTDE) in the mol ratio of approximately 0.7 MDA : 0.3 DAP : 1.0 BTDE. The precursor, produced using the esterification and spray drying procedures described in U. S. Pat. No. 4,296,208, contained about 1.5 weight percent of organosilicon dispersant. Prior to each run the precursor powder was well mixed for 30 minutes using a rolling jar mill. The foaming operations were conducted in a 5 kW microwave (2450 MHz) oven. A slab of polyimide foam 25.4 mm (one inch) in thickness covered with a heat-resistant Teflon resin coated glass cloth was placed below the bed of polyimide precursor. In Example I a free foaming procedure (no mold) was used whereas in Examples II-IX a quantity of the powder (700g) was placed inside a 0.3 X 0.3 X 0.6m (1' X 1' X 2') microwave transparent mold, foamed using a microwave power level of 1.4 kW for 20 minutes followed by an additional 10 minutes at 2.5 kW. The artifacts formed in molds were removed therefrom and in each run, these foamed structures or artifacts were cured to polyimide foams in a circulating air thermal oven at 260-288 °C (500-550 °F) for 30 minutes.

EXAMPLE I

Approximately 200g of dry precursor powder was spread on a sheet of PVC film and another sheet of this film was placed on top of the precursor. The so-encased bed of precursor was placed in the microwave oven and a power level of 2.5 kW was applied for 6 minutes. The whole bed of precursor rose nearly all at

once and a very fast foam rise occurred. The resultant foam structure was about one-third larger than normally achieved from the same quantity of precursor with no film covering. The foamed structure was cured for 30 minutes at 288 °C (550 °F) the convection thermal oven. The polyimide foam so produced had a very nice homogeneous cell structure.

EXAMPLE II (Baseline)

In this run the powder (700g) was laid in the mold and foamed directly without any additional treatment. The resulting cured polyimide bun contained a 15.2-17.8cm (6-7") deep cavity in the bottom along the entire length of the bun.

EXAMPLE III

In Example III the powder bed was covered with polyvinyl chloride film prior to placement of the mold in the microwave cavity. The resulting cured bun had a smaller cavity than the bun of Example II, being only 7.6-10.2cm (3-4") deep. In Example III the normal hard dense outer skin was eliminated, and more of the precursor powder participated in the foaming.

EXAMPLE IV

Using a procedure similar to that of Example III, various types of plastics films were evaluated. Two runs were made using PVC films from different manufacturers. A third run was made with polyvinylidene chloride film and another run involved use of a polyethylene film. Foams of good quality were formed in each case.

EXAMPLES V and VI

For Examples V and VI, plastics bags were prepared from two different films, the polyimide precursor powder was placed inside the bags, and the bags were tightly sealed. The precursors were then subjected to microwave radiation while inside these bags. The materials and results are summarized in the following table:

TABLE

Example	Film Type	Film Thickness, (in.) mm	Bun Quality
V	PVC	(0.0005) 0.0127	Excellent bun, virtually perfect.
VI	PE	(0.002) 0.0508	Good bun, but small because the film bag restricted expansion of the foam. A few small pinholes and striations.

The results in the above table indicate that the polyimide precursor can be bagged, stored, and then foamed while remaining in the bag, provided the bag is large enough to accommodate the size of the expanded foam or is made of a suitable flexible material that can stretch to accommodate the expanding foam without imposing undue constrictive forces upon the expanding foam.

Claims

1. Method of producing a foamed polymer structure wherein a polyimide precursor is exposed to microwave radiation of intensity sufficient to cause the development of a foamed polymer through the generation and evolution of gaseous material within the precursor as it foams which process comprises
   - maintaining the polyimide precursor and the foam as it is developing therefrom under a substantially vapor-impermeable microwave-compatible shroud that does not substantially restrict or impede development of the foam and prevents the surface of the foam from drying out and becoming hard and crusty as it would if left exposed.

2. Method according to claim 1 wherein said shroud is a polymer film.

3. Method according to claim 2 wherein said polymer film is a polyvinyl chloride film.

4. Method according to any of the claims 1 to 3 wherein said polyimide precursor comprises a lower alkyl ester of a tetracarboxylic acid and at least one primary diamine.

5. Method according to any of the claims 1 to 4, said method additionally comprising maintaining said precursor and the foam as it is developing therefrom, concurrently with subjecting it to microwave radiation, under an atmosphere enriched in vapors of a C_1 to C_4 alkanol.

6. Method according to any of the claims 1 to 5, said method additionally comprising preventing at least a substantial portion of the exposed surfaces of said precursor and the foam as it is developing therefrom, concurrently with subjecting them to microwave radiation, from drying out by keeping such surfaces wetted by a C_1 to C_4 alkanol in a quantity insufficient to impede the development of the foam.

7. Method according to any of the claims 1 to 6, said method additionally comprising the step of curing the developed foam into a polyimide foam.

8. Method according to claim 7 wherein said curing into a polyimide foam is carried out in a thermal oven.

9. A bun of cured polyimide foam produced by the method according to any of the claims 1 to 8.

Patentansprüche

1. Verfahren zur Herstellung einer geschäumten Polymerstruktur, bei dem ein Polyimidvorläufer einer Mikrowellenstrahlung von ausreichender Intensität ausgesetzt wird, um die Entwicklung eines geschäumten Polymers durch Erzeugung und Evolution von gasförmigem Material innerhalb des Vorläufers beim Schäumen auszulösen, wobei
   - der Polyimidvorläufer und der sich daraus entwickelnde Schaum unter einer im wesentlichen dampfundurchlässigen, mikrowellenkompatiblen Hülle gehalten werden, die die Entwicklung des Schaums nicht wesentlich beschränkt oder behindert und verhindert, daß die Oberfläche austrocknet und hart und krustig wird, wie es der Fall wäre, wenn man sie ungeschützt ließe.

2. Verfahren nach Anspruch 1, bei dem die Hülle ein Polymerfilm ist.

3. Verfahren nach Anspruch 2, bei dem der Polymerfilm ein Polyvinylchloridfilm ist.

4. Verfahren nach einem der Ansprüche 1 bis 3, bei dem der Polyimidvorläufer einen Niedrigalklyester einer Tetracarbonsäure und mindestens ein primäres Diamin umfaßt.

5. Verfahren nach einem der Ansprüche 1 bis 4, bei dem der Vorläufer und der sich daraus entwickelnde Schaum während der Mikrowellenbestrahlung zusätzlich unter einer mit Dämpfen eines C_1 bis C_4-Alkanols angereicherten Atmosphäre gehalten werden.

6. Verfahren nach einem der Ansprüche 1 bis 5, bei dem außerdem verhindert wird, daß zumindest ein wesentlicher Teil der freiliegenden Oberflächen des Vorläufers und des sich daraus entwickelnden Schaums während der Mikrowellenbestrahlung austrocknen, indem man diese Flächen mit einem C_1 bis C_4-Alkanol benetzt, und zwar in einer Menge, die nicht ausreicht, um die Schaumentwicklung zu behindern.

7. Verfahren nach einem der Ansprüche 1 bis 6, bei dem der entwickelte Schaum außerdem zu einem Polyimidschaum gehärtet wird.

8. Verfahren nach Anspruch 7, bei dem die Härtung zu einem Polyimidschaum in einem Wärmeofen erfolgt.

9. Laib aus gehärtetem Polyimidschaum, der nach dem Verfahren gemäß einem der Ansprüche 1 bis 8 hergestellt wird.

Revendications

1. Procédé de production d'une structure cellulaire en polymère, dans lequel un précurseur de polyimide est exposé à un rayonnement par micro-ondes d'intensité suffisante pour provoquer le développement d'un polymère cellulaire par génération et dégagement d'une matière gazeuse au sein du précurseur à mesure qu'il se transforme en mousse, le procédé comprenant
   - le maintien du précurseur de polyimide et de la mousse à mesure de son développement à partir du précurseur sous une enveloppe compatible avec les micro-ondes, principalement imperméable à la vapeur, qui ne limite pas ou ne gêne pas notablement le développement de la mousse et empêche la surface de cette dernière de se dessécher et de durcir en formant une croûte comme si elle était laissée à découvert.

2. Procédé suivant la revendication 1, dans lequel l'enveloppe est un film de polymère.

3. Procédé suivant la revendication 2, dans lequel le film de polymère est un film de polychlorure de vinyle.

4. Procédé suivant l'une quelconque des revendications 1 à 3, dans lequel le précurseur de polyimide comprend un ester alkylique inférieur d'un acide tétracarboxylique et au moins une diamine primaire.

5. Procédé suivant l'une quelconque des revendications 1 à 4, comprenant en outre le maintien du précurseur et de la mousse au fur et à mesure qu'elle se développe à partir de ce dernier, en les exposant simultanément au rayonnement par micro-ondes, sous une atmosphère enrichie en vapeurs d'un alcanol en C_1 à C_4.

6. Procédé suivant l'une quelconque des revendications 1 à 5, qui comprend en outre l'opération consistant à empêcher au moins une portion importante des surfaces exposées du précurseur et de la mousse, à mesure qu'elle se développe à partir ce dernier, tout en les soumettant ensemble à un rayonnement par micro-ondes, de se dessécher en faisant en sorte que ces surfaces restent mouillées par un alcanol en C_1 à C_4 en une quantité insuffisante pour gêner le développement de la mousse.

7. Procédé suivant l'une quelconque des revendications 1 à 6, comprenant en outre l'étape de maturation de la mousse développée en une mousse de polyimide.

8. Procédé suivant la revendication 7, dans lequel la maturation en une mousse de polyimide est effectuée dans un four thermique.

9. Pain de mousse de polyimide mûrie, produit par le procédé suivant l'une quelconque des revendications 1 à 8.